Evolution of Wielka Śnieżna Cave in the light of geomorphologic observations

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ABSTRACT

Wielka Śnieżna Cave is the largest Cave System in Tatra Mts. The vertical elements of the cave have been regarded as of Pleistocene age which developed on tectonic discontinuities formed after the glacier retreat and they have not been modified by water. Some observations in that cave revealed that among vertical forms which preserved their original, tectonic character there are also shafts which have been modelled by corrosive and mechanic activity of water, as they reached the circular cross-sections.

Genesis of horizontal level of Wodociąg may be related to short period of stabilization of erosion base at this level, because its width does not exceed 2 m. Such not significant size may result also from the peripheral position of Wielka Śnieżna in relation to the drainage point.

A zone of distinct morphology composed of waterfalls with some loops and bypasses stretches below Wodociąg. It developed in epiphreatic conditions, influenced by fresh, unsaturated waters. At the present these passages are mechanically shaped within the vadose zone. Hydrogeological conditions of this zone have changed several times since its creation. During certain periods of Pleistocene it was plugged by sediments.

Wielka Śnieżna Cave is a polygenetic system, composed of some independently developed elements, joint into one formation in the course of evolution. One group of these elements has not been modelled by water and preserved its original tectonic character, but the other has submitted to some processes of erosion and chemical corrosion in different conditions. Explaining of genesis of such complex systems as Wielka Śnieżna, requires precise separate surveys for each of the components.

KEY WORDS: high-mountain karst, speleomorphology, speleogenesis.

Introduction

Problem of the Tatra’s vertical caves genesis remains still open, in spite of many years of studies. Despite this cave has been explored since late 50-s, it has not been scientifically elaborated enough, and the main part of literature data is limited to some general statements. Unclear are still the questions of decisive factors responsible for the creation of the vertical and horizontal cave elements as well as speleogenetical role of glaciers and corrosion intensity of water in different hydrogeological zones of the system.

According to the main part of ideas, the vertical elements of the Tatra’s caves were formed mainly on tectonic discontinuities which were hardly modelled by proglacial waters, because of their low aggressivity (Grodzicki 1970, 1991; Wójcik; 1978; Głazek et.al., 1979; Kicińska, 2002). Development of Wielka Śnieżna Cave is related to Late Pleistocene (Pulina, 1962; Głazek et.al., 1979; Grodzicki, Głazek, 1996) or to the beginning of Pleistocene (Rudnicki, 1967). Wójcik (1978) claims that proglacial waters flew through this cave during glaciation of Riss, basing this thesis on the sediment observations. M. Pulina (1962) regards the influence of chemically aggressive water from melting glaciers during
postglacial periods as essential factor in that cave development. Z. Wójcik (1978) defines this cave as a poligenetical form, recognizing the role of tectonic detention of rock masses during Pleistocene and Holocene as a dominant factor in this form creation. According to this author, this system was remodelled by proglacial waters. Nad Kotlinami Cave is an older part, as its genesis was influenced by leakage of water from the crystalline cap-rock. It was later included to the system. J. Glazek et al. (1979) claim that this cave is one of proglacial type, not modelled by corrosion and it was created when the Tatra’s valleys were incised to the present deepness. D. Kicińska (2002) the horizontal elements of this cave defined as much older and suggested their relation to the other ancient cave levels of the Lodowe Źródło Cave System.

Geomorphic observations carried out in Wielka Śnieżna Cave reveal that previous ideas concerning genesis of the vertical caves should be verified, because among numerous elements of preserved tectonic character, there are also typical shafts, genesis of which was related to strong corrosive and mechanic modelling.

In foreign literature taking up similar topic, the ideas explaining origin of the cave vertical elements are often contradictory. There are concepts which define these elements as older than Pleistocene (Audra, 2004) and the role of glacier in the process of creation them is of minor importance. The other explain that the shafts are very young and even 4000 years is a sufficient period to create a shaft of 10 m in diameter (White, 2000; Palmer, 2001).

Questionable is also the issue of the age and evolution of the horizontal elements of the cave systems in Western Tatra Mts. which are regarded as Neogene forms (Rudnicki 1967; Wójcik, 1966, 1968; Glazek & Grodzicki, 1996). The horizontal passage of Wodociąg, Kicińska (2002) connected with the most ancient caves of the Lodowe Źródło System: Miętusia Wyszenia Cave and Czarna Cave. By analogy with the oldest cave levels in the Pierre Saint Martin region (PSM, Pyrenees) defined as of the Miocene/Pliocene age it is possible to look at the problem of the age of the Tatra’s caves and their probable evolution in a new light.

### Location

Cave System of Wielka Śnieżna is located in Czerwone Wierchy Massif (Red Hills Massif) in the Western Tatra Mts. (Fig.1). It consists of five caves: Nad Kotlinami Cave (1875 m a.s.l.), Jasny Aven Cave (1852 m a.s.l.), Śnieżna Cave (1700 m a.s.l), Wilcza Cave (1672 m a.s.l.), and Wielka Litworowa Cave (1906 m a.s.l.) (Fig.2). Entrances to the caves are located in upper parts of Mała Łąka Valley and in Litworowa Valley, above the glacial cirque bottoms of Wyszenia Świstówka and Litworowa Valley. The Cave System is drained to the West, by Lodowe Źródło spring (998 m a.s.l.) located in Kościelecka Valley.

![Fig. 1. Location of the Cave.](image-url)
From the geological point of view, Tatra Mts. consist of three main units. These are: the crystalline core with parautochthonic rock cover, the „High-Tatric zone” of the Czerwone Wierchy Nappe and the Giewont Nappe, and two „Sub-Tatric zone”. Wielka Śnieżna Cave System developed in the lower Triassic and middle Triassic limestones and dolomites of the Czerwone Wierchy Nappe. This nappe is divided into two units (Organy and Żdziary) separated by Organy fault (Kotański, 1961, 1963; Bac-Moszaszwili, Nowicki, 2006). The abundance of the caves in this area is explained by the intensive tectonic processes in the area of the Organy fault (Bac-Moszaszwili, Nowicki, 2006). The entrance to the cave is located about 500 m from the crystalline cap-rock (Fig. 3). The uppermost passages of this cave between 1700 and 1675 m a.s.l. used dislocations in the carbonate Anisian rock. Below, up to 1575 m a.s.l. Wielka Studnia formed which is characterized by a cylindrical shape and a flat bottom based on the dolomitic series. Below, in these series the inclined corridors of „Płytowce” developed, which are characterized by tectonic features.

Geological setting

Wielka Śnieżna Cave has developed on stratification planes and vertical discontinuities (Grodzicki, Kardaś, 1989; Bac-Moszaszwili, Nowicki, 2006). In the Cave’s cross section there are some levels conditioned by structural and tectonic factors. The majority of the shafts developed in highly tectonized part of the massif related to Organy fault (Bac-Moszaszwili, Nowicki, 2006).
The most evident level of that cave is formed by Wodociąg Corridor at the altitude of 1400 m a.s.l. This level is a great collector, gathering waters from the vertical parts of the cave. It was created on Organy fault (Bac-Moszaszwili, Nowicki, 2006). The corridors of the lower parts are directed by the inclination of strata. The dips decrease in the lower parts of the cave, from 53°S at the altitude of 1300 m n.p.m. to 25°E at about 1100 m n.p.m. (Grodzicki, Kardas, 1989). As M. Bac-Moszaszwili and T. Nowicki (2006, Fig. 4) suggest these parts are related to the main fault of Organy, too.

Fig. 4. Relation of the Śnieżna Cave passages and Organy fault (after M. Bac-Moszaszwili, T. Nowicki, 2006).

Cave geomorphology

Cave System of Wielka Śnieżna is characterized by a branched passage pattern that is a result of separate ponor points. In vertical extent of the cave, it is possible to distinguish at least two parts of different morphology. The upper one consists of vertical elements that join the horizontal passage of Wodociąg at the altitude of 1400 m a.s.l. Lower located parts create a system of inclined corridors, loops and waterfalls.

One of the most typical vertical elements of the upper part of the Cave is Wielka Studnia (Great Shaft). It is a particular form of regular, circular cross-section. The shaft has developed vertically between 1570 and 1630 m a.s.l., it is 68 m deep and 12 m in diameter. It owes a flat bottom and a shelf perched about 2 meters above (Fig. 5). There is also a window in the Shaft’s wall opened to a perched corridor about 20 meters above the bottom (Fig. 6).

Below, in dolomitic series the inclined corridors of „Płytowce” extent, which developed as planes, inclined 60-70° (Fig. 7). They preserved their tectonic character. At the altitude of 1400 m a.s.l., an evident level of Wodociąg developed, using transverse fracture of EW direction (Fig. 8). In Wodociąg and below, some remnants of previous sediment infilling were observed (Fig. 9). There are also some paragenetic forms preserved on the ceiling, which is a prove of previous infilling too (Fig. 10). Wodociąg is a narrow passage, that is around 1,5 – 2 meters wide. It has been shaped to a key cross-section by waters which dissolved the scallops on its walls (Fig. 11). Below, till the terminal passages of the cave, there are five waterfalls, the highest of which exceeds 40 m. Some of them owe their longer, dry bypasses. These corridors developed in epiphreatic conditions by the impact of fresh,
undersaturated flood waters. At present, they are shaped by corrosive and mechanic erosion of water with a rocky load. There are marmits with crystalline pebbles at the foot of the waterfalls. Surface of more inclined thresholds is covered by karrens. Present epiphreatic zone is about 100 m thick, as the mud sediment covering the walls of the passages indicates.

Fig. 5. Flat shelf above the present Shaft’s bottom, as a relict of the previous bottom level.

Fig. 6. Window in the Wielka Studnia walls that can be a mark of a previous shaft bottom level.

Fig. 7. Płytowce corridor based on dolomitic series as the example of subvertical corridor that preserved its tectonic character.

Fig. 8. Cross-section of Wodociąg Corridor (after J. Grodzicki, 1970).

Fig. 9. Sediments preserved in Wodociąg as registration of previous different hydrogeological conditions.
Phreatic zone is between terminal siphons at the altitude of 1100 m and Lodowe Źródló Spring at the altitude of 998 m. Difference of water chemistry between these two points is not significant as well, therefore we can assume that corrosive capacity of water within the phreatic zone is not important.

Wielka Śnieżna Cave’s evolution

System of Wielka Śnieżna Cave consists of numerous elements of different genesis, which have been joint together in the course of its long evolution. Simplified genetical division into young, Pleistocene vertical elements and older horizontal conduits, perched above present valley bottom do not work in this case. Among vertical elements hardly modelled by water, there are also the shafts, which creation required the influence of numerous factors and processes changing in time. One of the examples of such elements is Wielka Studnia which has the form of a vertical tube. Taking advantage of the known rates of chemical denudation in the shafts zone of the Lodowe Źródló Spring cave system, it was calculated that during 10000 years, only 100 m³ of a rock mass could have been removed from the walls of Wielka Studnia characterized by the volume around 7000 m³ (Pawłowska-Bielawska, 2007). This value is the result of calculations based on the rate of denudation in the zone of shafts of Czerwone Wierchy Massif, estimated as 7 m³·km⁻²·year⁻¹, as in the zone of shaft takes place only 20% of general massif denudation (Pawłowska-Bielawska, 2005, Pulina et.al., in print). According to water chemistry analyses, majority of water corrosive potential is used in epikarstic zone. Corrosion alone in conditions similar to the present ones, has not been able to create such huge dimensions of the shaft in 10000 years. Therefore the other theoretical explanations of genesis of that shaft were overviewed in another paper (Pawłowska-Bielawska, 2007), which have driven the author to deduction, that the beginning of the formation of the shaft most probably took place in the early Pleistocene. It could not have been hollowed out by dissolving later, as it was revealed by the calculations based on the present rate of denudation and because of limited activity of water in the glacial periods. It is also unlikely, that it developed earlier, because the zone of
its creation was much deeper than currently, below a thick cap-rock which had not been eroded than. At present it is located about 70 meters below the topographic surface. During Neogene, about 200 meters thick cap-rock above an initial Wielka Studnia, probably hindered speleologenetic processes enlarging this form. Nevertheless, its initial form could be dissolved by concentrated aggressive water flow draining from crystalline cap-rock as it exists among the forms which later submitted to similar conditions but they do not reveal cylindrical shape. In later stages of the evolution of Wielka Studnia it was enlarged mainly by corrosional activity of condensation water and mechanic erosion. The proves of the strong mechanic modelling are remains of previous higher located bottoms preserved as flat shelves (Fig. 5) and perched above the present bottom windows to abandoned channels which were related to the level of an ancient bottom. Such window is located 20 m above the present bottom of Wielka Studnia (Fig. 6). In the part of the cave called Partie Za Kolankiem (Fig. 12) the form of a particular chimney developed, which is vertically divided into two sections by a great marmite. Water flow uses a cut through in the partition of this marmite. In further evolution the partition would probably be destroyed by corrosion and erosion, and the only evidence of previous marmite would be a flat shelf. Similar forms are present also in another cave system, Foran del Muss (Canin, Julian Alps, Fig. 13). These facts advocate the thesis of the important mechanic erosion role in the process of shafts enlargement.

Below the zone of vertical elements, at the level of 1400 m a.s.l., the horizontal conduit of Wodociąg developed. It was probably modelled during short period of the erosion base stabilization at this altitude, as not significant dimension of this corridor suggest. Its small dimensions can be also the effect of
peripheral location of this cave in relation with the draining spring. This level is concordant with the most ancient cave levels in Western Fig. 14. Cave level in Śnieżna Studnia Cave which can indicate the period of tectonic stabilization in Wielka Śnieżna Cave evolution (W-E cross section, adopted from: http://www.sktj.pl/epimenides/index_d.html).

Tatra Mts. The upper passage of Czarna Cave developed at similar altitude, and it is defined as of the phreatic origin of Upper Miocene age (Głazek, Grodzicki, 1996). The age of the oldest dated speleothem from Czarna Cave is estimated at 1 mln years (Nowicki et al., 2000). However, taking into account the parameters and morphology of Wodociąg, it is difficult to accept the concept of its so ancient origin. In Pierre Saint Martin Massif Region (PSM, Pyrenees, France/Spain) the horizontal passages of the caves developed at the altitudes of 1900, 1500 and 1300 m a.s.l. are regarded as of the Miocene/Pliocene age (Maire, 1990). It makes denivelation around 1500, 1100, 900 m above the actual drainage base. Wodociąg, as well as the other ancient cave levels of the system, are located barely 400 m above Lodowe Źródło Spring. It suggests that the rate of the Tatra Mts uplifting is 2-4 times slower than of the Pyrenees or the age of the oldest cave levels in Tatra Mts. can be exaggerated. Oryginal phreatic tube of Wodociąg has been remodeled in vadose conditions, as it is of a keyhole cross-section at the present.

During the next stage of the cave development, accelerated after the base level lowering, the lower level was incepted. There are not evident horizontal level between Wodociąg and the level of present phreatic zone. However erosion could be stabilized at the altitude of 1250 m a.s.l., which is registered as the level in Śnieżna Studnia Cave (Fig. 14) developed in the neighborhood with Wielka Śnieżna Cave. It can not be excluded that it belongs to the Wielka Śnieżna Cave System, however it has not been proved so far. Nevertheless flooding waters impacted the passages modelling in the whole zone below Wodociąg. The results of this impact are numerous bypasses of the waterfalls and loops, currently remodeled in vadose conditions. In the further evolutionary stage the base level rising caused the clogging of the cave by sediments. They retained partially as the cemented planes on the Wodociąg level as well as in the corridors located below. The other evidence of the cave partial infilling by sediments are paragenetic forms in Wodociąg (Fig. 10). At present, in this zone the active processes of erosive incision, evorsion and corrosion shape the passages. Epiphreatic zone is about 100 m thick which is enlarged mainly during the floods by corrosive activity of fresh waters.

Phreatic zone is rather shallow, as the flow from the terminal siphon to Lodowe Źródło Spring which are 4600 m away from each other, goes on in 7 days (Dąbrowski, Rudnicki, 1967). It is zone of lower chemical activity, as the difference between the amounts of dissolved solids in these two points is not considerable.
Conclusion

Wielka Śnieżna Cave is a polygenetic system, composed of numerous, independently developed elements, joint together in course of evolution. Inception of vertical shafts of this cave was related to aggressive waters dissolutorial activity along favored fissures in the rock mass, most probably on the contact with the crystalline cap-rock. Calculations based on the rate of denudation in the shafts zone indicate that the process of shafts formation is complex, long-lasting and supported by mechanic impact of water bearing a rocky load. Differently were shaped vertical conduits developed on tectonically enlarged fractures. Highly tectonized rocks in dislocation zone of Organy fault influenced the directions of the systems development (Bac-Moszaszwili, Nowicki, 2006). Proglacial waters used tectonic predispositions, flowing through the voids rapidly, hardly changing their original morphology. Horizontal level of Wodociąg could be created at the terminal phase of the base level stabilization or analogically to the other old cave levels of the Lodowe Źródło Spring, but the peripheral location limited the abundance of waters which could not generate its significant volume. It developed on tectonic discontinuity (Bac-Moszaszwili, Nowicki, 2006) and was periodically flooded by waters flowing to the West (Kicińska, 2002). Next, as it reached the keyhole cross section it has been modelled within the vadose zone.

The zone below Wodociąg developed due to the influence of fresh epiphreatic waters that generated the system of numerous loops and bypasses. At present, this part of the cave is modelled in vadose conditions, mainly by mechanic erosion of water with a rocky load. Waters of present phreatic zone are not very important in the speleogenetical processes. The flow between the terminal siphon and the Lodowe Źródło Spring is rather fast as the distance of 4600 m is covered in 7 days. Not significant difference between the total solids dissolved in waters from these two points, suggests that corrosion processes in this zone are not very intensive.

Geomorphic observations and results of water chemistry analyses in Czerwone Wierchy Massif’s interior, reveal that the most important speleological role play the extreme processes, acting in short piece of time but with an important power. During the main part of a year, cave enlarging processes are almost not active. This tendency is also applicable in the geological scale, as there were some geological periods favorable for the cave development, and the other, that rather inhibited these processes. Glacial erosion was important because it uncovered the carbonate rock, and it is likely that the shafts incision followed the changing range of the crystalline cap. The genesis of vertical caves is a result of superimposing different factors impact, which acting separately would not give visible result.

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